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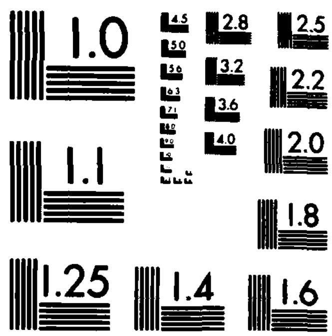

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FINAL REPORT

Construction of a High Energy Linear Accelerator for Research in Free Electron Lasers, Beam-Wave Interactions, Spectroscopy and Microcircuitry Fabrication

Air Force Contract
No. AFOSR-83-0303

1 August 1983 to 31 July 1984

Principal Investigators: J. M. J. Madey
M. R. Yearian

Abstract

A long pulse, high brightness 45 MeV linear accelerator has been constructed for use as a driver for free electron laser and beam-wave experiments, and as the first section of a 1 GeV injector for a high-brightness electron storage ring.

Table of Contents:

1. Introduction:

In November 1982, as part of the DoD University Instrumentation Program (URIP), we proposed to acquire the components for eight sections of a 1.0 GeV electron and positron linear accelerator to be used for free electron laser and beam wave research, and synchrotron radiation research in spectroscopy and microcircuit fabrication. The estimated cost of these components was $1.0 million.

Our proposal was motivated by our interests in proceeding with the development of effective and economical linear accelerator and storage ring facilities to support advanced FEL research, and the application of FEL's and synchrotron radiation to Stanford's DoD supported basic research programs. The effort to develop these facilities began in 1977 with an Army-sponsored design study of the storage ring technology required to support high gain and high efficiency short wavelength FEL operation. The results of the design study were highly encouraging. In addition to our own continuing interest in the technology, the design developed in the study was subsequently adopted to improve the brightness of the electron and positron beams in the SLAC linear collider project.

But the electrons in a storage ring must be injected into the ring from another accelerator, and the characteristics of the accelerator used as an injector can strongly affect the current attainable in the ring and the overall system reliability. Ideally, electrons should be injected into the ring at the operating energy, and at a current and current density which is adequate for rapid and efficient injection. For this purpose we proposed to construct a pulsed 1.0 GeV linac using the accelerator sections of the High Energy Physics Laboratory's mothballed MKIII linac. The accelerator sections

of the MKIII, which had last operated in the early 1970's, are identical to the SLAC structure, and are nearly ideally suited to serve as an injector for the storage ring.

The major doubts concerning the MKIII sections arose from the oil contamination which had occurred as a consequence of past vacuum pump failures. If the accelerating gradient were limited by this contamination, it might not be possible to reach the required energy for injection, or alternatively, an excessive number of modulators and klystrons might be required.

To evaluate the condition of the MKIII sections, we undertook (under AFOSR contract F49620-82K-0022) to test two of the contaminated sections under the operating conditions anticipated in the new linac injector. While contamination was found to limit the accelerating gradient in the sections as they were removed from the MKIII, it proved possible to attain the required gradient by an _in situ_ bakeout at 350°C. Our experience in these tests, and particularly, our experience in constructing the modulator and RF system for these tests, formed the basis of our estimates of the component cost in our University Research Instrumentation Proposal.

The actual award received under the URIP program was $300,000., somewhat less than 1/3 of the funds required to assemble the eight sections we had proposed. In response to this reduction, we revised our objectives to concentrate on the most critical portion of the linac, the first section. In our proposal, this section was conceived to operate both as the first section of the storage ring injector, and independently, as a source of 20-50 MeV electrons for low energy FEL and beam-wave experiments. The specifications for this section are

thus more stringent than for the remaining sections of the linac. In particular, the first section must:

1. operate at pulse lengths up to 10 μsec, as compared to 1.5 μsec for the rest of the sections
2. have an energy spread and phase stability compatible with the stringent requirements for FEL operation
3. operate at high average current and the lowest possible vertical and horizontal emittances.

In view of the special requirements for this section, and the near-term FEL and beam-wave experimental plans which had been made for it, it was decided to apply to available URIP funds to acquire the components required to bring the section into operation. These components included:

1. a new 30 megawatt klystron with a modified cathode designed to operate at pulse lengths as long as 12 μsec
2. a 12 μsec, low ripple, EMI shielded modulator for this klystron
3. the waveguide and vacuum flanges required for this section, the electron gun, and the remaining eight sections
4. a residual gas analyzer to monitor the vacuum in the old MKIII sections as they were baked out.

2. <u>Research Results</u>

The components and instrumentation described above was acquired and, with the support of AF contract AFOSR-83-0303, assembled to construct the first section of the linac. Tests of this system have confirmed most of our design objectives, specifically:

1. the modulator and klystron have operated to produce peak RF power outputs of up to 30 megawatt peak power output at pulses up to 12 μsec in length with an amplitude ripple below 0.1 dB, and a phase ripple below $\pm 2^{\circ}$;
2. the high power RF distribution system, including the high power windows and gas filled waveguide acquired in this program, have operated at this power level and pulse length without failure for more than 1000 hours to date;
3. when operated with the microwave gun developed with the support of AF contract AFOSR-83-0303, the linac has delivered up to 300 mA current with a normalized emittance $\beta\gamma\varepsilon$ less than 7π millimeter-milliradian. The resultant current density, $<2>/(\beta\gamma\varepsilon)^2 = 4 \times 10^5$ A/cm^2 is equal to the best density ever attained in a microwave linac.

The major difficulty experienced to date with the system has been the fault rate of the hydrogen thyratron used as a high power switch for the pulse forming network in the new modulator. At a repetition rate of 20 Hz the thyratrons failed to turn off about once every 2-4 x 10^4 pulses, causing an excessive current drain from the modulator's dc power supply and an overcurrent trip. The manufacturer of these thyratrons, ITT, has promised to rebuild the tubes at no cost to correct the problem.

Following its assembly, the linac has been used extensively to support a number of ongoing and new research programs. These include:

1. The development of a hgih brightness microwave gun, funded by Air Force contract AFOSR-83-0303. (Principal Investigator: A. Schwettman and J. Madey.)

2. The development of a compact infrared FEL, funded by AROD contract DAAG-84-K-0144. (Principal Investigator: J. Madey.)
3. An experimental study of high gain and diffraction effects, employing the compact IRFEL, funded by ONR contract N00014-85-K-0535. (Principal Investigators: J. Madey and D.A.G. Deacon.)
4. A biomedical research program employing the compact IRFEL, funded by Army contract DAMDD-85-G-5038. (Principal Investigator: J. Madey.)
5. An experimental study of electron beam propagation in high pressure gasses, and of gas loaded FEL operation, funded by DoE contract DEFG03-84-ER-13275. (Principal Investigator: R. Pantell.)

In addition to the research programs, it is anticipated that several new research programs using this system will be begun in 1986. These include:

1. a cooperative industry-university research program with Rockwell International to study the physics of tapered wiggler free electron lasers
2. a cooperative industry-university research program with Bell Communications Research to study the non-linear absorption and susceptibility of III-V, II-VI, and quantum well semiconductor materials and devices using our compact IRFEL
3. a multidisciplinary research program in materials science to exploit the peak power, pulse structure, and tuneability of the infrared FEL in the study of molecular relaxation, optical fiber fabrication and evaluation, and electronic materials.

In addition to these individual research programs, the system will also be used to inject an electron beam into the succeeding sections of the linac and into the 1 GeV FEL storage ring as these systems are brought into operation in 1987 and 88.

The first section of the linac was assembled for its initial tests, and the initial research described above, in the Main Bay of the High Energy Physics Lab to take advantage of the shielding and utilities which had been installed for the old MKIII linac. These tests were concluded in October, 1985.

The first section, together with the remainder of the linac and the 1 GeV storage ring, will be permanently installed in End Station III of HEPL. It is expected that the first section of the linac will resume operation in ESIII in March, 1986.

3 New Discoveries

The new discoveries made using the instrumentation and components acquired with this contract include a number of new accomplishments in accelerator physics and technology, and a number of accomplishments in FEL and general beam-wave research. With respect to accelerator physics and technology, this contract has led to:

1. demonstration of the highest gradient and longest pulse length yet achieved in a 3 meter S-band SLAC-type travelling wave accelerator section; and
2. demonstration of the high current and high current density attainable through the use of a strong microwave field to replace the dc electric field usually used in linac electron guns.

With respect to FEL and general beam-wave physics, the contract has led to:

1. demonstration of the highest gain attained to date at near-infrared wavelengths in an FEL amplifier or oscillator; and
2. demonstration of the absence of plasma instabilities in the propagation of a picosecond, repetitively pulsed, high current electron beam through hydrogen gas at pressures from 1-1000 mm.

The high level of continuing activity proposed for this equipment, and its modest operating costs, make it likely that it will continue to be a key element in our FEL, beam-wave, and synchrotron radiation research programs.

4. Staff

The scientific and technical staff responsible for the installation, assembly, and test of the instrumentation acquired in this contract include:

John Madey, Professor (Research) of Electrical Engineering and High Energy Physics (Principal Investigator)

Marcel Marc (Project Engineer)

Glen Westenskow (Research Associate)

Steve Benson (Graduate Student)

Jean Lebacqz, Adjunct Professor (Emeritus), Stanford Linear Accelerator Center (Consultant)

5. Publications

The results of the infrared FEL and gas-loaded FEL programs described above will be published in the Proceedings of the 1985 Granlibakken FEL Conference. The results of the microwave gun development program will be published in Particle Accelerators.

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